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Geomagnetic Effects in the Dark Hemisphere Associated with Solar Flares

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1. Introduction

The sudden short lived perturbation in geomagnetic variation in the sunlit hemisphere concurrent with the occurrence of a solar flare referred to as 'Solar flare effect' (SFE) or 'crochet' is rather a well-studied aspect in the field of solar-terrestrial relations ever since it was discovered that chromospheric eruptions, short wave fade-outs (SWF's) and SFE's were all concomitant phenomena (DELLINGER, 1935, 1937a, b; FLEMING, 1936; RICHARDSON, 1936; TORRESON *et al.*, 1936a, b). It is now known that the occurrence of SFE is a maximum around local noon and its amplitude has a local time variation similar to that of Sq field (MCNISH, 1937; NAGATA, 1952; SUBRAHMANYAM, 1964; PINTER, 1967). Evaluation of ionospheric current systems during flare times revealed that SFE is not due to a mere augmentation of normal Sq field as thought of by CHAPMAN (1937, 1961) and CHAPMAN and BARTELS (1940); and the current flowing layer responsible for SFE is below the normal dynamo current carrying region (VOLLAND and TAUBENHEIM, 1958; VELDKAMP and VAN SABBEN, 1960; YASHURA and MAEDA, 1961). An interpretation of SFE in terms of enhanced electrical conductivity due to solar X-ray flare flux enhancement in the band 1–20 Å was made by OHSHIO (1964) from a study of selected SFE events observed during I.G.Y. A recent study indicated that SFE is due to extra ionization produced by solar XUV (1–1000 Å) flare radiation and the SFE's often exhibit a composite structure consisting of a 'fast' component presumably due to EUV radiation (100–1000 Å) and a 'slow' component produced by soft X-rays (1–100 Å) (RICHMOND and VENKATESWARAN, 1971). A very recent study made by the authors using SFE's observed (on normal run magnetograms) at Kodaikanal (Lat: 10.2°N; Long: 77.5°E, Dip: 3.5°N) showed that the amplitude of SFE is linearly correlated with peak solar X-ray flux level in the bands: 1–8 Å and 8–20 Å (monitored by SOLRAD-9) lending support to the interpretation that SFE is due to enhanced ionization produced by solar soft X-rays (SASTRI and MURTHY, 1975).

It is generally considered that solar flare effect on geomagnetic variation occurs only in the sunlit hemisphere. The first direct evidence to the possibility that SFE's do occur in the dark hemisphere also was presented a decade ago, by OHSHIO (1964). He noticed the amplitude of the night time SFE's to be small and their shape to be not so distinct even at the maximum stage as in the sunlit part of the world. He interpreted these night time geomagnetic effects of the solar flares as due to induction currents that were forced to flow in the ionosphere on the dark side of the earth owing to the sudden increase in electrical conductivity of the sunlit hemisphere. An examination of magnetogram data (normal run) of Kodaikanal, a station in the electrojet, over a three year period (1969–1971) showed several instances during night time when there are conspicuous short-lived perturbations in geomagnetic elements (usually in H component). These perturbations are noticed to occur mostly ($\approx 75\%$) in concurrence with both Solar X-ray flares (monitored by SOLRAD-9 and published in Solar-Geophysical Data) and sudden ionospheric disturbances in the sunlit hemisphere (Solar-Geophysical Data) and occasionally either with a solar X-ray flare or sudden ionospheric disturbances. This observation lends further evidence to the possibility that geomagnetic effects do occur in the dark hemisphere associated with solar flares, as first reported by OHSHIO (1964). A systemic study of these events is now being carried out by the authors, the preliminary results of which comprises this brief communication. Hereafter these events will be referred to as NTSFE (night time solar flare effect) while day time effects will be referred to as SFE throughout this paper.

2. Observational Results

A total of 40 well-defined NTSFE events observed over the three year period have been selected to work out their characteristics (rise time, total duration, amplitude and time correlation with solar X-ray flares). To facilitate a comparative study, the characteristics of a total of 56 SFE (day-time) events observed during the same period have also been evaluated. This shows at the first instance that NTSFE events occur more or less as frequently as SFE events. In Plate 1 are shown some typical examples of NTSFE events noticed in our magnetogram data. It can be seen that the signatures are clearcut and have a well-defined shape and sufficient amplitude in H component in most cases (at the maximum). Further the effect is clearly discernible even during disturbed conditions (for example, the event of 23 October, 1970). These features differ from the earlier observations of OHSHIO (1964) who reported the NTSFE's to be small in amplitude and not to exhibit a distinct shape even at the maximum stage; and this could be due to the fact that in the present study the night time

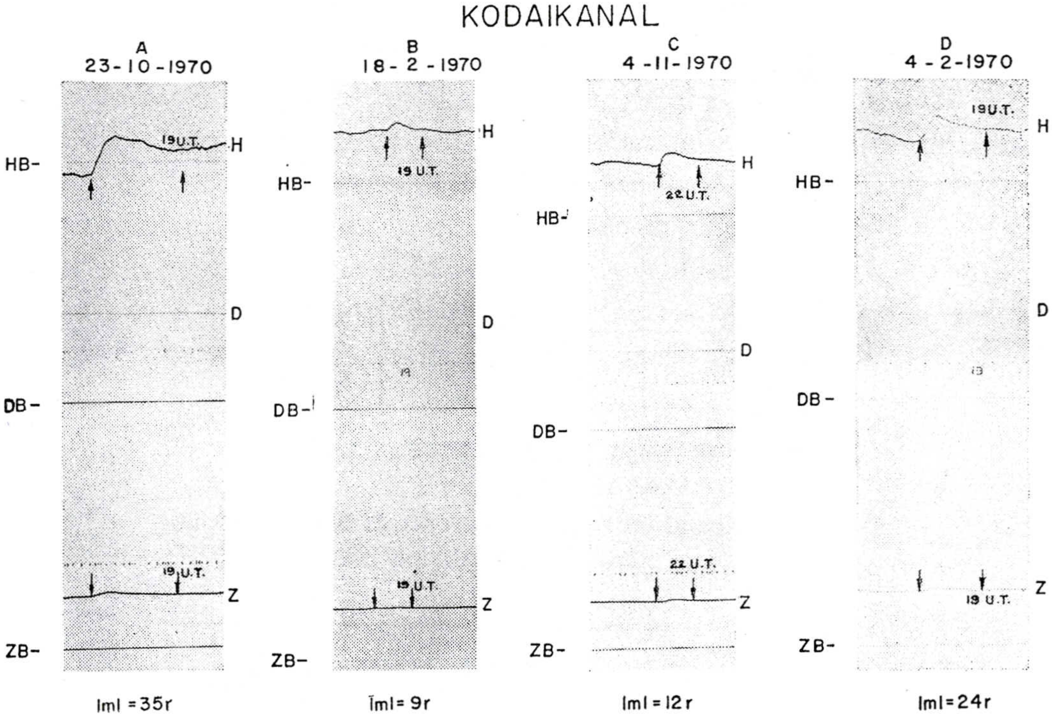

Plate 1. Typical examples of NTSFE events observed at the equatorial station: Kodaikanal.

$|m|$ – Amplitude of NTSFE in γ ($\gamma=10^{-5}$ Gauss)

A: 23.10.70, $A_p=29$; Associated with both solar X-ray flare and SID's: Solar X-ray flare (1–8 Å) 1656–1721–1745 U.T.; SID's. 1711–1716–1740 U.T.

B: 18.2.70, $A_p=9$; Associated with both solar X-ray flare and SID's 1804–1812–1845 U.T.

C: 4.11.70, $A_p=7$, Associated with both solar X-ray flare and SID's: Solar X-ray flare: (1–8 Å) 2209–2210–2229 U.T.; SID's 2140–2148–2240 U.T.

D: 4.2.70, $A_p=12$; Associated with only solar X-ray flare: Solar X-ray flare (1–8 Å) 1716–1718–1723 U.T.

(after Solar-Geophysical Data)

geomagnetic effects of solar flares are studied at only one station: Kodaikanal, situated in the equatorial region where relatively strong eastward electric current flows generally even at night during geomagnetic solar flare effect, while in OHSHIO's (1964) work the night time geomagnetic effects were studied at various stations scattered in the dark hemisphere where the electric current flow should be relatively weak.

In Fig. 1 is presented the local time variation of occurrence frequency of the NTSFE events. It may be seen that the occurrence is a maximum around midnight and is more or less symmetrical around the maximum but for a secondary peak in the interval 2000–2100 hrs. In Fig. 2 are shown the distributions of the rise time and total duration of NTSFE events are also shown for comparison. It is evident that NTSFE events are characterized by slower rise

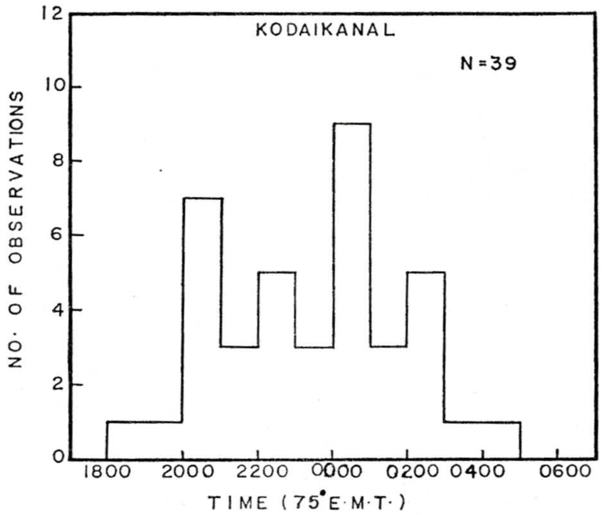

Fig. 1. Distribution of the occurrence of NTSFE events observed at Kodaikanal over the period 1969–1971.

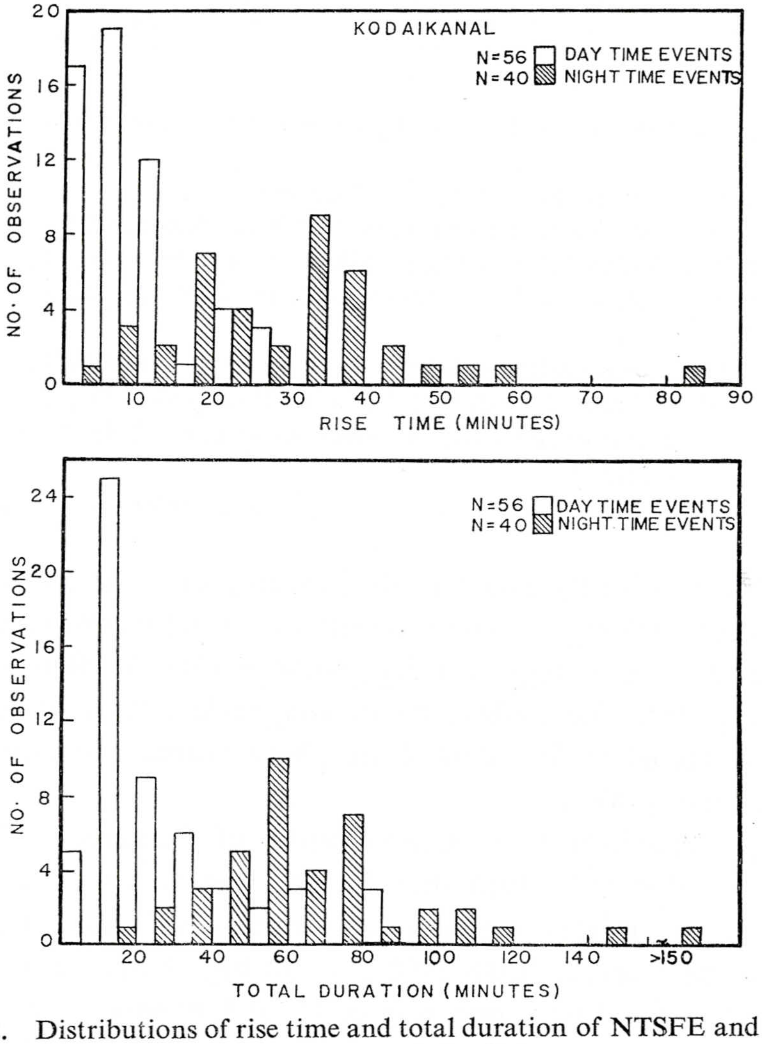

Fig. 2. Distributions of rise time and total duration of NTSFE and SFE events (Each class interval of NTSFE and SFE events is of 5 min).

and slower-decay compared to SFE events. The average value of the rise time and total duration for NTSFE events are 28.7 min and 66.6 min respectively, while the corresponding values for SFE events are 9.1 min and 26.5 min. A study of the characteristics of NTSFE in relation to those of the associated solar X-ray flare events showed that the amplitude of the NTSFE is independent of the peak solar X-ray flux level in the two bands: 1–8 Å and 8–20 Å. This behaviour is in contrast to that of SFE events whose amplitude is linearly correlated with peak solar X-ray flux level in the two bands: 1–8 Å and 8–20 Å (Sastri and Murthy 1974). In Fig. 3 is shown the time correlation of NTSFE

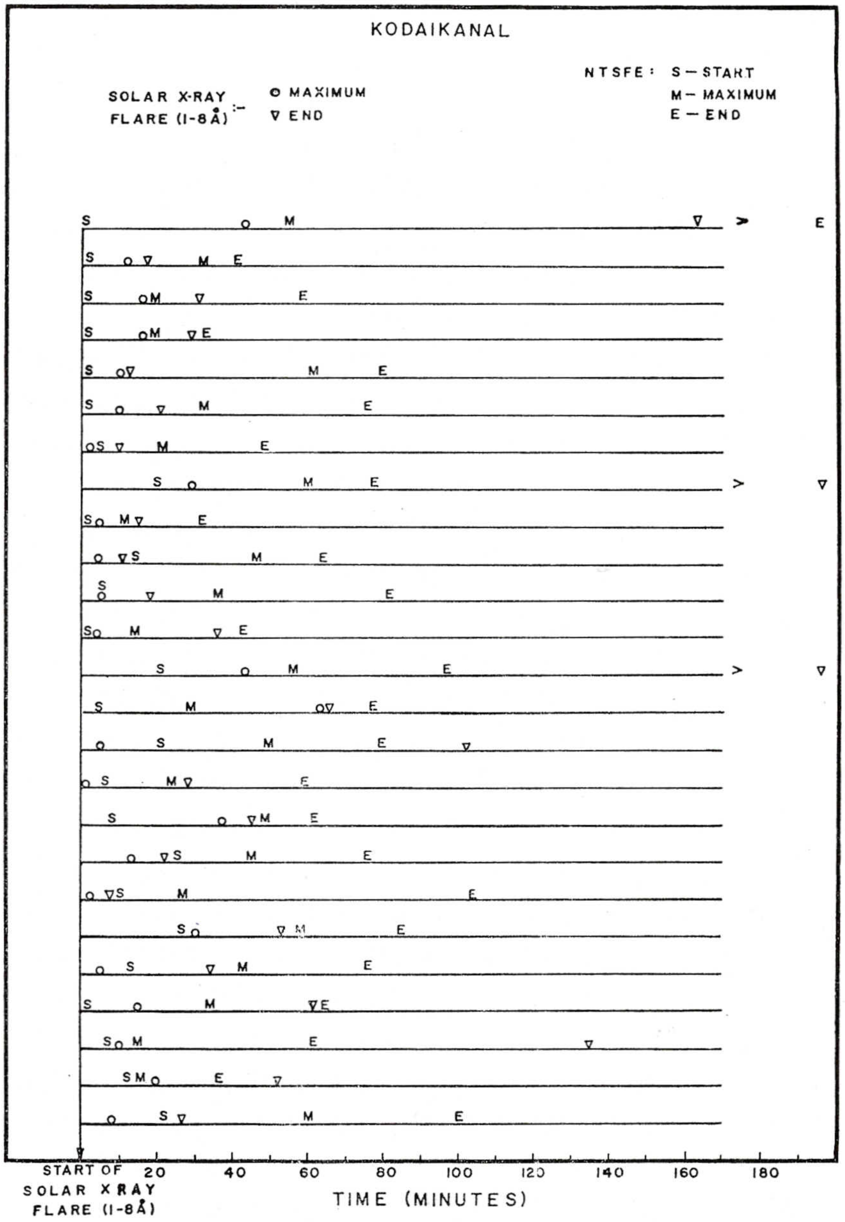

Fig. 3. Time correlation of NTSFE events with solar X-ray flares (1–8 Å).

events with those of solar X-ray flares (1–8 Å). (We have presented only 25 events as for the rest of the events we have noticed from the hourly profile of solar X-ray flux (1–8 Å) published in Solar-Geophysical Data that the occurrence of the solar X-ray flare is immediately preceeded by satellite night period). Firstly, the NTSFE event starts after the start of the solar X-ray flare and the maximum of the NTSFE event usually occurs after the maximum of the solar X-ray flare. The time difference (usually lag) between NTSFE maximum and solar X-ray flare maximum varies over a wide range 1 min–52 min and no definite variation of this time lag with the time of occurrence of the NTSFE event is noticed. Secondly, the duration of the NTSFE even is in general more than that of the X-ray flare.

3. Discussion

In the preceding section, observational evidence is presented to show that geomagnetic effects do occur in the dark hemisphere also in association with solar flares. It is found that the characteristics of these NTSFE events significantly differ from those of SFE events observed at the same station. As regards the physical process responsible for NTSFE events, Ohshio (1964) advanced the interpretation that they are due to currents induced into the dark hemisphere due to enhanced electrical conductivity in the sunlit hemisphere in order to make closed electric current in the ionosphere surrounding the earth. Following the work of Rikitake and Yukutake (1962), who treated the geomagnetic solar flare effect as a world wide transient phenomenon, Ohshio (1964) calculated the time lag and intensity of geomagnetic solar flare effect due to electromagnetic induction. He found that a weak current flows in the dark hemisphere and that its intensity is about 20% of that in the sunlit hemisphere and reaches a maximum over the globe in about 0.5 to 1.0 min after the sudden increase in conductivity in the sunlit hemisphere. The results presented above do not seem to support Ohshio's interpretation as the time lag between the solar X-ray flare maximum (responsible for enhanced electrical conductivity in the sunlit hemisphere) and NTSFE maximum varies over a wide range (1–52 min) and is usually larger than that expected based on Ohshio's calculations, and this discrepancy might be mostly due to the mathematically idealised calculation made by Ohshio (1964) besed on a model such as suddenly enhanced electric conductivity without duration. A definite conclusion as regards the plausible mechanism responsible for NTSFE events awaits a further study of geomorphology for selected events, using data from a number of stations both in the sunlit and dark hemispheres. Such a study is being made by the authors, the results of which will be reported later.

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Use is made of the following data:
Solar-Geophysical Data ESSA/NoAA, Boulder, Colorado, U.S.A.